

RADIO INSTITUTE OF AMERICA

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Technical Lesson 13

POWER TRANSFORMERS

You became acquainted with the principles underlying the alternating current transformer in your study of induction and its different characteristics. Before studying transformers it will be necessary for you to recall that which you learned in your study of self-induction, and it is suggested that you again go over the lesson dealing with that part of the work to refresh your memory in order that the fundamental action of the transformer may be thoroughly understood.

The transformer comes into use when we wish to change a voltage of low value to one of higher value or to change high voltages to voltages of lower values. These changes may be accomplished in the coils of the transformer at high efficiency and without the aid of moving parts.

First let us consider the construction of a simple transformer core, then the windings or coils and finally determine how it works and the numerous uses we have for it in radio practice.

THE SIMPLE TRANSFORMER

A simple transformer can be made as follows: Upon a soft iron ring wind a few turns of ordinary rubber covered wire. Opposite to this winding and on the same rings wind a large number of turns of insulated fine wire as shown in Figure 1. The first winding is called the primary winding and the second is called the secondary winding.

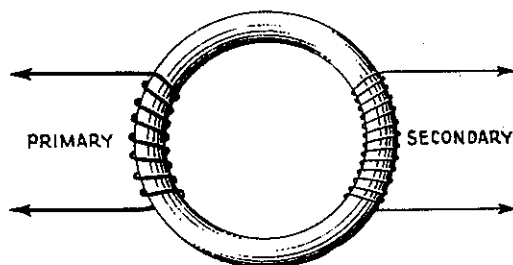


Figure 1

In your work on electro-magnetic induction you learned that when current passes through a wire a magnetic field immediately expands about the wire, and that when this field cuts another wire an E.M.F. is at once induced in the second wire. If the second wire forms a closed circuit this induced E.M.F. produces a current which flows through the second closed wire. You also learned that, in order to produce this induced E.M.F. these magnetic lines of force, or the field, must be in a state of continual change.

PRODUCTION OF INDUCED E.M.F.

Let us pause here and review the various ways this can be accomplished by referring to Figures 2A, 2B, 2C and 2D. In Figure 2A the magnetic lines of force are constant. In this field is a closed conductor represented by the small circle. When this conductor is moved through the field in a straight line, as from "S" to "F", or from "F" to "S", it will be moving parallel with the lines of force. As a result none of the lines of force have been cut and, therefore, no induced E.M.F. takes place in the conductor.

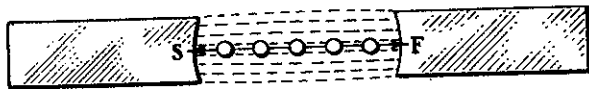


Figure 2A

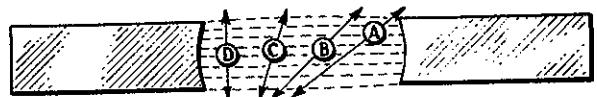


Figure 2B

In Figure 2B we have represented the conductor as moving through, or cutting, the lines of force at four different angles. If we move "A" through the field at ever so slight an angle the lines of force will be cut and an induced E.M.F. results. "B" will cut more lines of force in a given time than "A" because it travels through the field more nearly at right angles than does "A" and a greater induced E.M.F. therefore results in conductor "B" than in "A". "C", likewise, will have induced in it a greater E.M.F. due to the increased angle at which it cuts the lines of force. When the conductor moves through a magnetic field at right angles, as shown at "D", the maximum number of lines of force are cut (providing all the wires are moved at the same rate or in the same given time), resulting in the maximum induced E.M.F. This in-

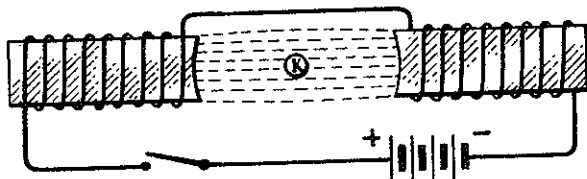


Figure 2C

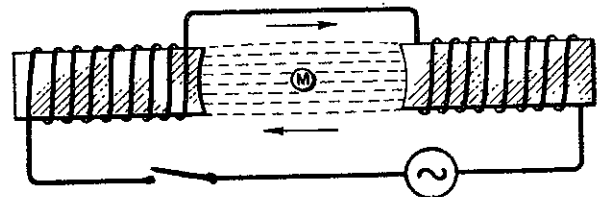


Figure 2D

duced E.M.F. may be increased by increasing the field strength or by increasing the speed of the conductors, or both.

Figure 2C represents a conductor "K" in an electro-magnetic field. The conductor is stationary but the lines of force of the field are made to expand and contract (rise and fall) in the space about the conductor by opening and closing the switch which does not allow current to flow continuously through the electro-magnets, thereby causing the field to vary in strength. This will produce an induced E.M.F. in the conductor "K". This method will give the desired result but someone must open and close the switch continually or employ an automatic device such as a vibrator to do the same thing, which involves moving mechanical parts, and moving mechanical parts are preferably to be avoided because they are often a source of trouble.

If it is a matter of causing these lines of force to vary, why not use alternating current which is constantly varying in strength from zero to maximum and then decreasing to zero, only to repeat the same operation over again a fraction of a second later but in the opposite direction. This is not only possible, but can be and is done as shown in Figure 2D. Here the conductor is stationary whereas the magnetic field is constantly changing about the conductor "M" due to the increasing and decreasing nature of the alternating current supplied to the windings. An E.M.F. will be induced in wire "M" by the changing magnetic field although the wire does not move. The last method, then, is the one we will use in the transformers we are to employ in our radio circuits.

Transformers are used in the commercial field to send electric current from one part of the country to another over high tension lines. This energy can be sent many miles with small loss by employing step-up transformers and then reduced to any desired voltage by a step-down transformer. Its use, therefore, is by no means confined to radio.

The underlying principles, however, regarding the action of the commercial transformer and the types used in radio practice are the same.

Returning now to the transformer shown in Figure 1. If an interrupted direct current is applied to the primary winding an E.M.F. will be induced in the secondary winding which will be considerably higher in voltage than that used to energize the primary winding providing more turns are wound on the secondary than the primary.

The electromotive force induced in the secondary winding depends upon the ratio of the turns in the two windings, primary "P" and secondary "S", also on the rate this flux or field threading through and expanding about the secondary winding is changed.

Suppose the primary, "P" of a transformer is wound with one hundred turns of number 14 or 16 B & S gauge insulated copper wire. On the secondary, "S" many thousands of turns of number 36 B & S insulated copper wire is wound. Now, by applying a voltage, say of 100 volts, to the primary winding, a potential of many thousand volts will be induced in the secondary winding.

By making improvements in this fundamental design of the transformer, but using the same principles, we can construct what is known as the induction coil, which was shown and explained in your lesson on electromagnetic induction. The current in the primary of the induction coil can be interrupted from thirty to one hundred times per second by proper adjustment of the vibrator arm "V" and the adjusting screw "AS". The secondary of this induction coil is comprised of many thousand of turns of fine wire, whereas the primary is of comparatively few turns of coarse wire. Because of the high turns ratio of these windings the voltage induced in the secondary is very high; so high, in fact, that although the secondary terminals may be separated by a large air gap the voltage will be great enough to break down the resistance of the intervening air and "jump" across this air gap in the form of an electric spark.

TYPES OF POWER TRANSFORMERS

The symbol used to denote an iron core transformer is shown in Figure 3 and will be used hereafter whenever a transformer of this type is shown in a circuit.

Transformers may be classed as open core transformers and closed core transformers. The open core transformer is so called because the core does not provide a continuous magnetic path, or circuit, for the magnetic lines of force, i.e., the magnetic circuit, as provided by the iron core, is open. An open core transformer is shown diagrammatically in Figure 4 and a glance at this illustration will show that the magnetic lines of force have a magnetic circuit only partly through iron, the remainder of their path being, perforce, through air.

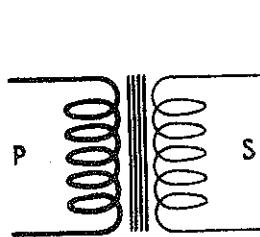


Figure 3

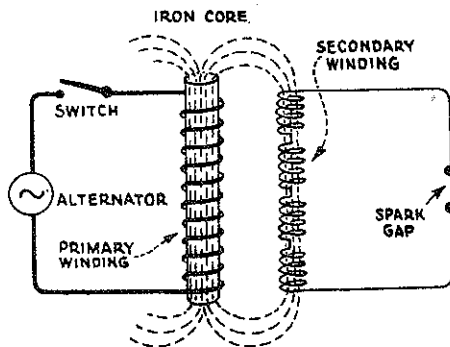


Figure 4

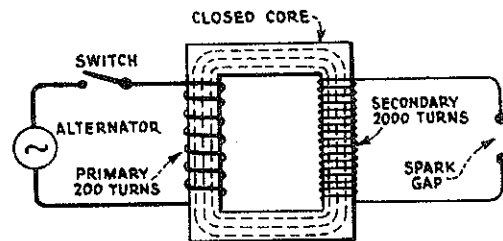


Figure 5

Compare this condition with that shown in Figure 5 wherein is illustrated a closed core transformer. It at once becomes evident that, in this type of core, the magnetic lines of force have a continuous, or closed magnetic path in which to establish themselves and, therefore, are not forced to take a path even partly in air. Hence a closed core transformer is one in which the iron core provides a continuous, or closed, magnetic circuit for the magnetic lines of force.

The method of transformation of energy is indicated when the transformer is classed as a step-up transformer or as a step-down transformer. Transformers are designed as either constant voltage or constant current transformers. The induction coil described in the lesson on electro-magnetic induction is a good example of the open core transformer. This type of transformer is still used for certain purposes, but for radio work it has been superseded by the closed core type. The open core step-up constant current transformer used in radio work is shown in Figure 4 and 9, and it is very similar to the "induction coil" type of transformer just referred to.

The iron core is built up of laminations in the form of many small soft iron wires cut to length and tied into a tight bundle. This bundle of wires is then covered with insulating material, such as empire cloth, over which is wound the primary winding. The primary usually consists of a comparatively few turns of heavy insulated wire.

The terminals of the primary winding are brought out to be connected later to the supply source, such as a 110 volt A.C. generator. Over the completed primary winding is placed a tube which acts as an insulator separating the primary and secondary windings and capable of withstanding heat. On this tube is wound many thousand turns of very fine insulated wire. This secondary is generally wound in separate coils and as they are slipped over the insulating tubing they are connected, one to the other, so that all the coils comprising the secondary are in series. This simplifies the repairing of the secondary, for should one coil burn out it can easily be replaced without the expense and work of replacing the entire secondary winding. The terminals of the secondary winding are brought out and connected to the spark gap as shown.

When the switch in the primary circuit of Figure 4 is closed the alternator at once impresses an alternating E.M.F. on the primary winding of the transformer. This in turn forces an alternating current through the coil and there results an alternating magnetic field, or flux. This flux at once induces a counter electromotive force in the primary winding which opposes that E.M.F. being applied to the circuit by the alternator. The counter E.M.F. becomes so strong that it very nearly succeeds in stopping the pressure being applied by the alternator, resulting in but a small current flowing in the primary.

The flux caused by this current has moved through the magnetic circuit provided by the iron core, out at the ends, and has passed through the secondary winding inducing an E.M.F. in the secondary winding. In the secondary winding a counter E.M.F. is also caused by the flux which opposes the flux of the primary. Now remember this:- As the flux of the secondary has to pass partly through air the opposition to the primary flux is not great, therefore, there is little magnetic reaction by the secondary upon the primary due to the lack of a continuous path of iron for the magnetic flux to pass through. The self-induction of the primary, due to this break in the magnetic path, remains nearly constant and, because of this fact, the current is practically the same at all times, regardless of whether the secondary is closed or open. This type of transformer, therefore, is often termed a constant current transformer.

In designing an open core transformer where the effect of magnetic leakage is used (magnetic leakage being the effect caused by the flux passing through a circuit partly composed of iron and partly through air) a slight alteration in the design is made, in that more turns are added in the secondary circuit than would be used in the closed core type.

The closed core type is shown in Figure 5 and is known as a constant voltage step-up transformer. It's action is similar to the open core transformer with the exception of the reaction of the secondary on the primary due to the iron core which both coils embrace and which will be explained. Closing the switch impresses the voltage of the alternator upon the primary windings resulting in current flow therein with its attendant magnetic field, or flux.

This field now produces two effects simultaneously. Due to self-induction it begins to exert a back pressure, or counter E.M.F., in the primary windings, tending to prevent any more current flowing in the primary due to the pressure of the alternator. It also magnetizes the iron core on which the secondary is wound; this magnetic flux in the core then passes through the windings of the secondary thereby inducing an E.M.F. in the secondary and the resulting induced current will then flow in the secondary, if this circuit is closed.

The induced current now produced in the secondary is in a direction opposite to the current of the primary and it produces a magnetic field which opposes the field of the primary and thereby weakens it. As the core in this type of transformer provides a complete magnetic circuit for the field of the secondary, it is clear that the magnetic field of the secondary will react strongly upon the field of the primary. The strength of this secondary field will determine to what extent the primary field will be weakened, and when weakened the self-induction of the primary is reduced. When this self-induced field of the primary is weakened more current can flow in the primary, therefore, each increase in the secondary current causes an increase in the primary current and the same cycle of effects as took place at the start begins over again. With these effects taking place over and over again the voltage of the transformer is maintained fairly constant throughout the period of use.

A transformer having both the characteristics of the constant current and constant voltage transformer can be had if we provide an air gap which, while not as large as in the open core transformer, will provide an air space sufficient to allow a certain amount of magnetic leakage to take place. This can be done as is shown in Figure 6 by providing the core of the transformer with a magnetic leakage gap which will maintain the self-induction of the primary nearly constant under varying loads placed on the secondary.

The ratio of voltage in the secondary to that of the primary will be found to be nearly a direct ratio of the turns employed on each winding. For example, suppose the primary of the transformer of Figure 6 is composed of 200 turns of wire and the secondary has 2,000 turns; the voltage of the secondary will be $2000 \div 200$, or ten times greater than the voltage applied at the primary terminals by the alternator. This can be put in equation form as follows:

$$\frac{\text{EMF of secondary}}{\text{EMF of primary}} = \frac{\text{turns of secondary}}{\text{turns of primary}}$$

The primary winding in a step-up transformer receives the low voltage from the exciting force, or alternator, while the secondary winding delivers the high voltage induced therein by the action of the magnetic field produced by the current in the primary.

In the step-down transformer the reverse condition exists; the high voltage is applied to the winding of the greater number of turns and

this winding thereby becomes the primary, while the winding consisting of the lesser number of turns becomes the secondary. It is, therefore, good practice to refer to the windings of any transformer as the low tension and the high tension sides.

THE AUTO-TRANSFORMER

The auto-transformer is shown in Figure 7 and is seen to consist of the usual iron core on which is but one winding, this winding serving as both the primary and secondary of the device.

The transfer of energy from primary to secondary in the auto-transformer is not wholly inductive as in those types of transformers employing

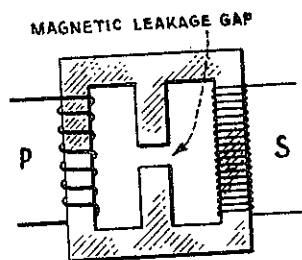


Figure 6

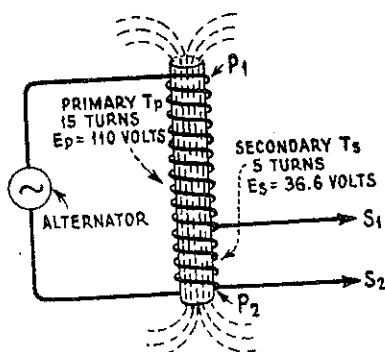


Figure 7

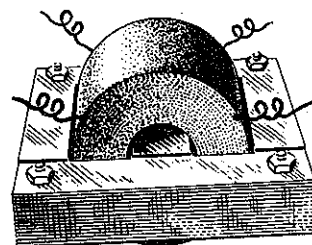


Figure 8

separate primary and secondary windings. In this type of transformer the transfer of energy from the primary circuit to the secondary circuit is partly conductive, as the secondary is an integral part of the primary winding, and partly inductive due to the inductive effect of the coil's magnetic field upon that part of the winding which comprises the secondary. This type of transformer is not used where the voltage transformation is large, i.e., where high voltages are to be stepped down to low voltages or, conversely, where low voltages are to be stepped up to high voltages. This is because of the liability of the voltage of the high tension side being impressed upon the low tension side due to the single winding being common to both the high and low tension circuits. Where the voltage transformation is large those types of transformers employing separate primary and secondary windings are used. Hence, when the auto-transformer is used, it is employed in circuits where the voltages being handled are of comparatively low values. For example, when stepping down 110 volts A.C. to, perhaps, 30 volts, or stepping up voltages from, say, 20 volts to 50 or 60 volts.

As in those types of transformers employing separate primary and secondary windings, the voltage developed in the secondary of the auto-transformer, as related to the primary voltage, is directly proportional to the ratio of primary to secondary turns. Therefore, the equation given on page 6 for the open core and closed core transformers can also be applied to auto-transformers. For example, in Figure 7 the auto-transformer is shown as having fifteen turns in the primary, five turns in the secondary and a primary voltage of 110 volts. What will be the secondary voltage?

According to the equation $\frac{E_s}{E_p} = \frac{T_s}{T_p}$. Substituting our known values

the equation becomes $\frac{E_s}{110} = \frac{5}{15}$, transposing, $E_s = \frac{5}{15} \times 110$ or E_s

equals $\frac{550}{15} = 36.6$. The secondary voltage, then is 36.6 volts.

If the alternator were connected to the terminals S1, S2, the five turn section of the winding would thereby become the primary and the 15 turn section would become the secondary. The voltage developed in the secondary can be found by the use of the same formula as before;

$\frac{E_s}{E_p} = \frac{T_s}{T_p}$ Substituting, we have $\frac{E_s}{110} = \frac{15}{5}$, transposing, $E_s = \frac{15}{5} \times 110$ or

$E_s = \frac{1650}{5} = 330$. The secondary voltage, then, is 330 volts.

SHELL TYPE TRANSFORMER

The shell type transformer is shown in Figure 8. The coils of the transformer are first wound on a suitable form and then, as is the case with all transformer windings, are thoroughly impregnated with an insulating compound. This may be merely melted paraffin or it may be a compound of paraffin, beeswax and rosin.

The iron core is now built around the windings. Laminated sections of iron are used and, after a sufficient amount of iron has been included, pressure is brought upon the laminated sections and rivets or bolts are then employed to hold them in place. Building the iron completely around the transformer windings provides a very complete circuit for the magnetic field.

Transformers are also employed in circuits wherein are flowing alternating currents of very high frequency, namely, radio frequency. These transformers, known as radio-frequency transformers, depend for their functioning upon the same basic principles as do power transformers but, due to the various phenomena encountered at radio frequencies, their design and construction differs greatly from that of power transformers.

Radio-frequency transformers play an important part in radio circuits and their construction and applications will be discussed in greater detail in a later lesson.

The transformers just described are power transformers and are used in circuits where high power is handled, yet transformers utilizing the same principles are employed in radio transmitters and receivers where such high power is not encountered.

TRANSFORMER LOSSES

The losses in a transformer are due to the heat created by the current passing through the windings which is generally termed the " I^2R loss" (current squared times the resistance loss). In transformers handling high power this heating effect may reach dangerous proportions, therefore various methods are employed to prevent the heat from rising to a point where the windings will burn out. The iron losses include hysteresis and eddy current losses.

Oil, grease, water and air are all employed to dissipate the heat developed in the transformer. When water is employed as a cooling

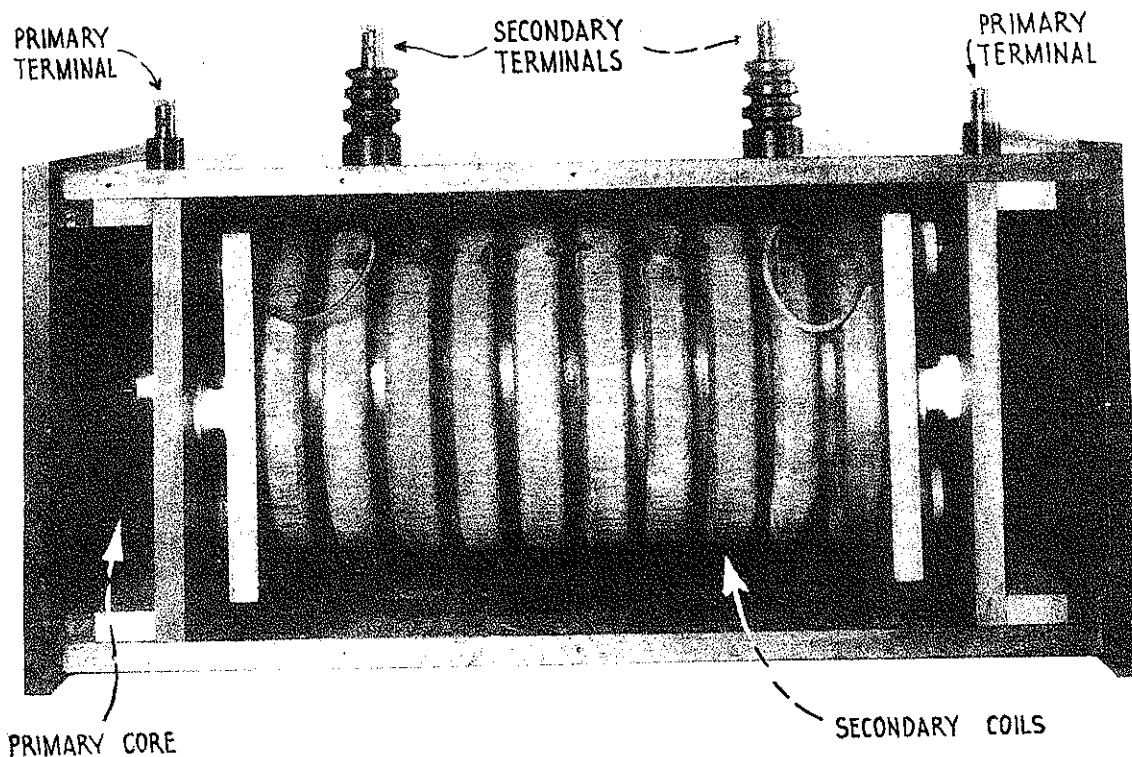


Figure 9

medium a cooling jacket is used in which the water circulates around the windings without coming in actual contact with the coils; the heat is taken up by the water and carried to the outside of the transformer case where it is radiated into the atmosphere.

When oil is used to dissipate heat it circulates, by virtue of thermal agitation, around the windings and is kept from coming in contact with the coils by the tape which covers the coils.

When air is used, it is forced to circulate about the coils by a fan, dissipating the heat by keeping cool air continually circulating through the windings of the transformer. Open core transformers of the type illustrated in Figure 9 are generally designed for primary voltages

of 110 to 500 volts at frequencies from 60 to 500 cycles, and secondary voltages of 12,000 to 15,000 volts, approximately.

A type of closed core transformer is shown in Figure 10. The coils are surrounded by the laminated core with the terminals brought out to a panel as shown. The safety gap leads are also brought out through insulators on the same panel.

The transformer is enclosed in a case which is filled with a heavy grease to prevent moisture from entering the windings and also to radiate the heat when the transformer is in use. The panel containing the terminals of both the primary, secondary, and safety gap, provides a top which is screwed to the case.

NO LOAD CURRENT

When a power transformer is in actual use the secondary of the transformer is closed through the load circuit and at this time current is flowing through both the primary and secondary windings. Disconnect the secondary terminals, however, and no current flows in the external circuit.

The alternating E.M.F. which is being supplied by the generator is still exerting itself on the primary and, being alternating E.M.F., the magnetic field produced is also alternating and continually changing. This causes a constant reversal of the magnetic flux through the iron core, which in turn threads through the primary winding inducing an E.M.F.

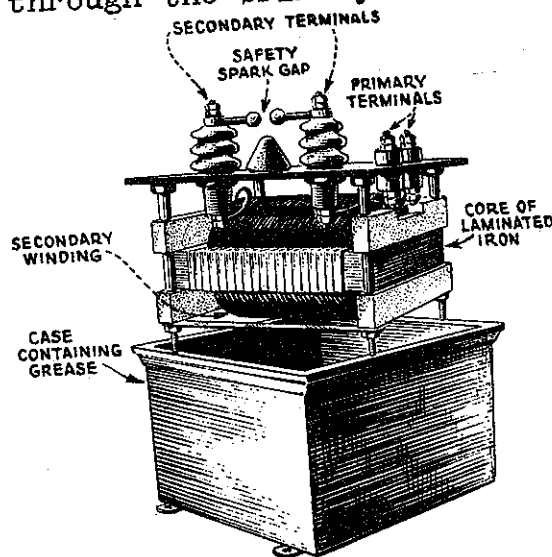


Figure 10

which is opposite to the applied E.M.F. This field or flux is also cutting the secondary but as the secondary circuit is open this back pressure will nearly equal the applied pressure of the alternator, therefore the primary current is very small. This small current in the primary is called the "no load current" and represents a very small

percentage of the current which is required by the transformer when it is on load.

From this it is seen the counter E.M.F. produced by the primary winding and which nearly equals the applied E.M.F. acts as a protective device against the short circuiting of the primary winding. Were it not for this back E.M.F., or self-induction, of the primary, the coil would be short circuited when on no load.

It is well to keep in mind the following facts when considering the transformer. First.- The transformer is primarily designed to change the voltage from a higher to a lower pressure, and vice versa. Second.- The frequency of the alternating current induced in the secondary is the same as that flowing in the primary. Third.- In radio communication high potentials are necessary and the transformer performs the duty of very efficiently changing low potentials to high without the use of moving parts. Fourth.- It is rugged in construction and will stand comparatively hard usage. Fifth.- It is most efficiently used on alternating current circuits. Sixth.- It does not convert alternating current to direct current, (a rotary converter is necessary for this work). Seventh.- Although the voltage is increased in a step-up transformer the actual power output is not increased, but is decreased to a slight extent. In other words in the transformation of one voltage to a higher some power is lost.

EXAMINATION - LESSON 13

1. Of what use is a transformer?
2. Describe a simple transformer.
3. (a) When the input of a transformer is 110 volts and the output 20,000 volts what name is given to the input winding? (b) What name, in this case, is given to the output winding?
4. Why are some types of power transformers immersed in oil?
5. Are transformers employed in electrical work in general, or for purposes other than radio? If so, for what purposes?
6. Draw a diagram of an open core step-up transformer. Explain its operation.
7. Describe a closed core transformer.
8. How is the ratio of voltage transformation of transformers determined?
9. What is an auto-transformer?
10. What are the principal losses in a power transformer?